An Integrated Solid-State LED Luminaire for General Lighting

January 30, 2008

The Department of Energy

Award Number: DE-DE-FC26-06NT42932

Principal Investigator: Kevin Dowling, Philips SSL

The Team

Kevin Dowling, PI

Philips Solid State Lighting

3 Burlington Woods, 4th floor

Burlington, MA 01803

Tel: 781.418.9236

Email: kevin@colorkinetics.com

Team Members

Fritz Morgan

Ihor Lys

Houayda Chamoun

Brad Kolsky

Ron Roberts

Ryan Williamson

Thomas Yuan

Cree, Santa Barbara Technology Center

340 Storke Road

Goleta CA

Tel: 805 968 9460

Email: Thomas_yuan@cree.com

Team Members

Bernd Keller

Monica Hansen

Arpan Chakraborty

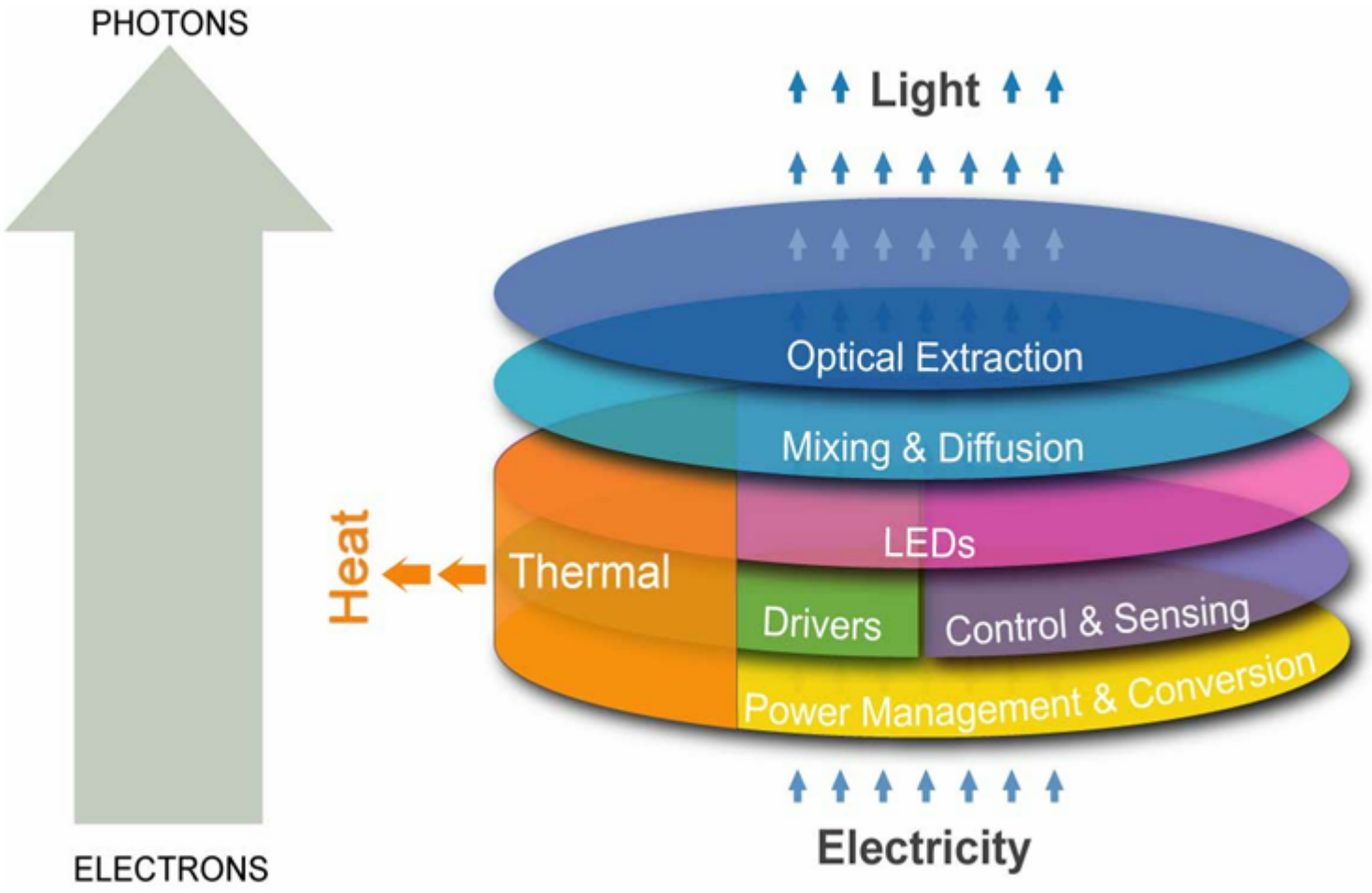
Goals

*This proposed program will address these issues by creating a high-efficiency light source **equivalent** to a 60W Edison-base A-lamp that will achieve substantial benchmarks in efficacy, cost, lifetime and performance.*

Program Goals

- 800 lumens
- 90 CRI
- 80 lpw

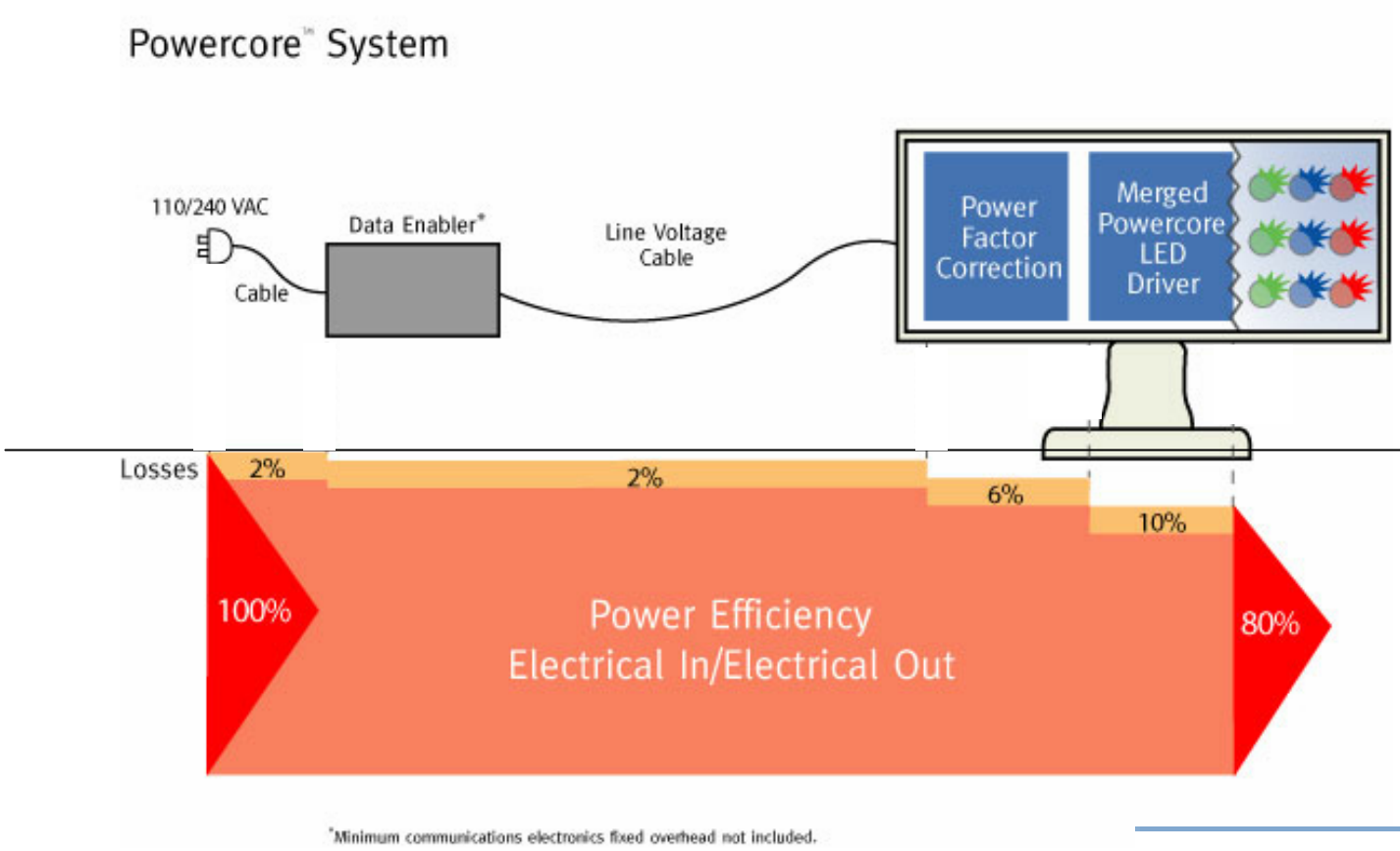
The Systems Approach



PHILIPS

CREE

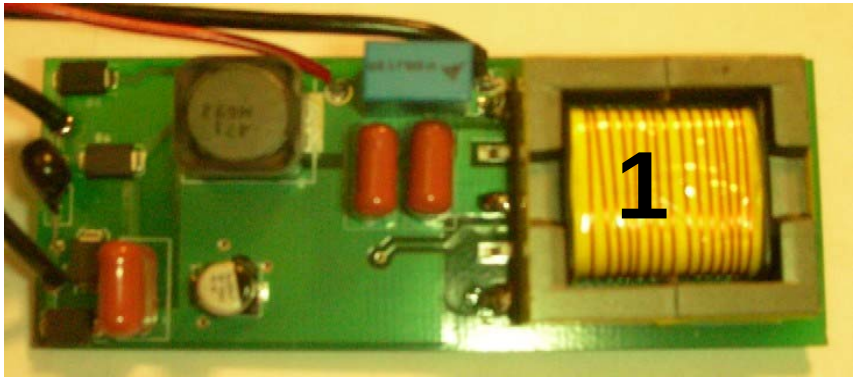
Power: Earlier Developments



POWERCORE™ BY COLOR KINETICS

Power Conversion & Drivers

- From Line voltage to LEDs using DSP control
- “Instant On” and dimmable.
- Achieving >92% efficiency (~0.9W for 10W system)
- Control each string of LEDs
- Except transformer all COTS
- Small parts count
- Metal film caps and one electrolytic



PHILIPS

CREE

Mechanical Configuration

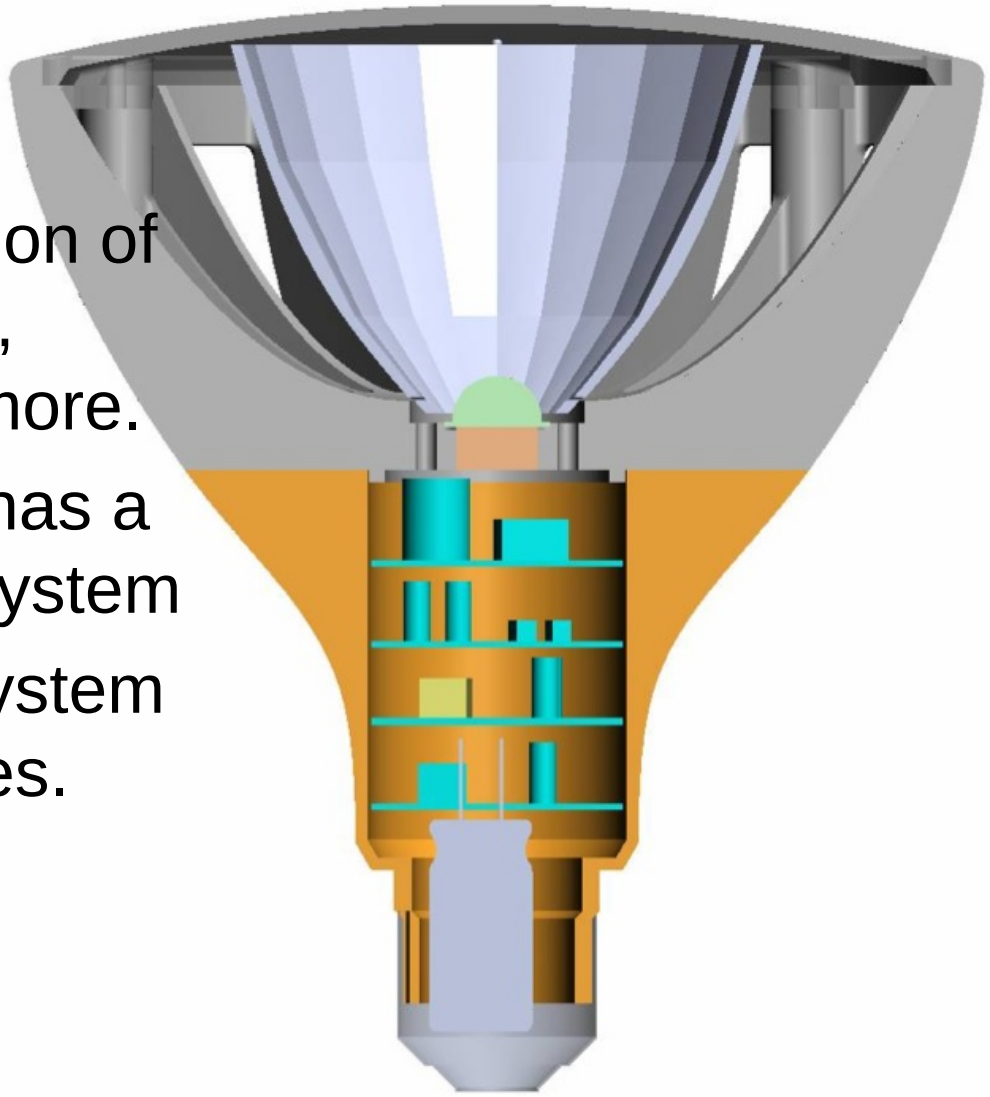
- Analyzed many configurations
- Key issue is managing thermal
- Assembly issues as well
- Maximize light output without compromising reliability

PHILIPS

CREE

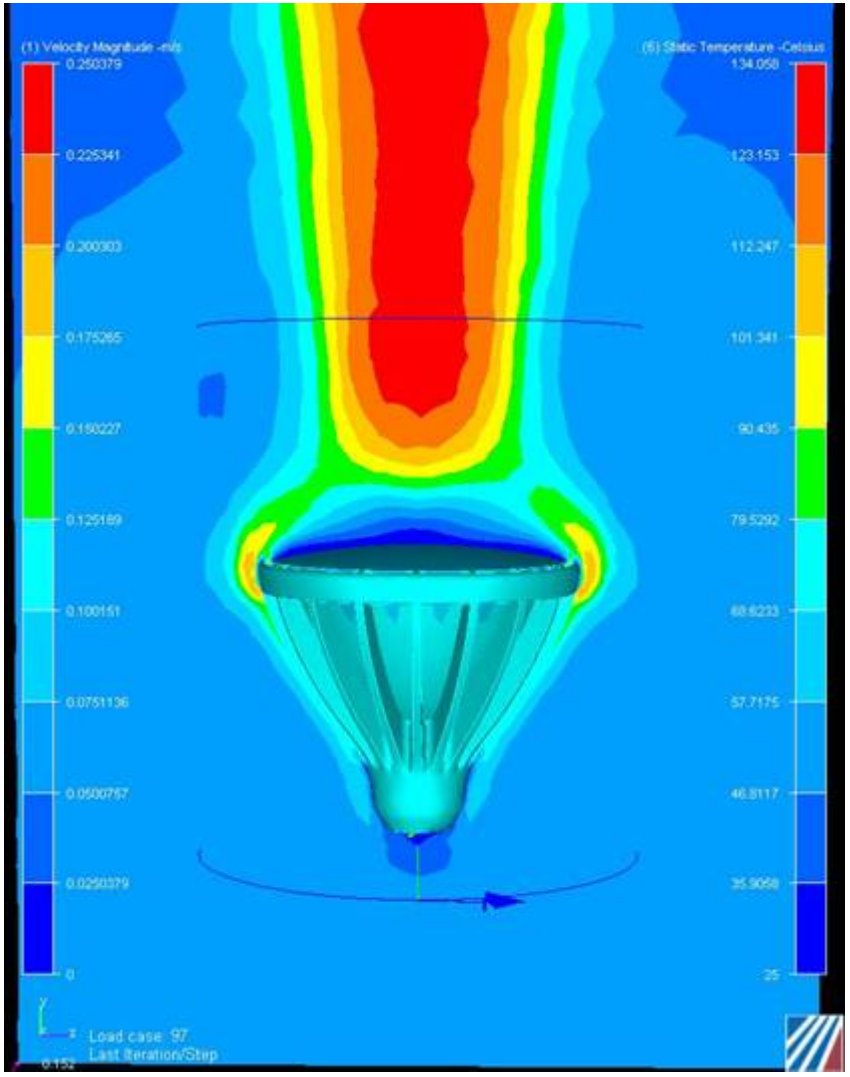
LED-based PAR 38

- Tightly coupled system
- An inter-related combination of thermal, optical, electrical, mechanical, control and more.
- A decision in any aspect has a ripple effect through the system
- Carefully analyzed with system model prior to any changes.



Thermal Management Progress

- Several iterations of thermal analysis.
- Developed ‘chimney’ effect for generating airflow without active means in all orientations
- Determining effectiveness in a variety of orientations and developing worst case scenarios
- Issue lessens with improved efficacy

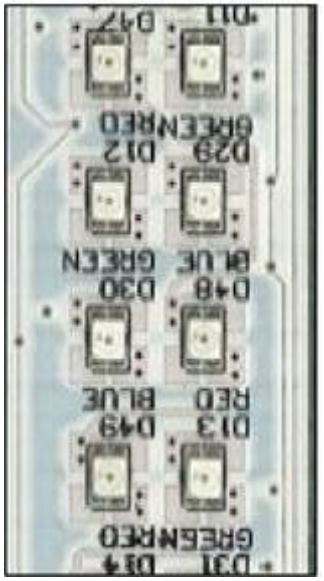


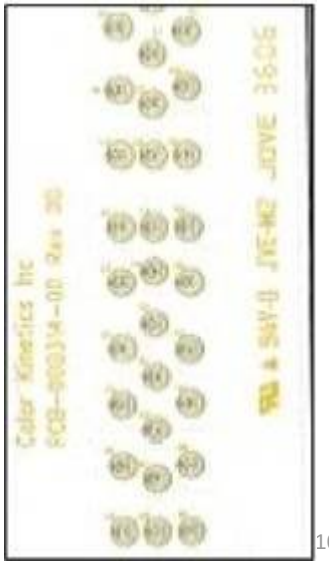
PHILIPS

CREE

LED Approach - Larger Number of Small Die

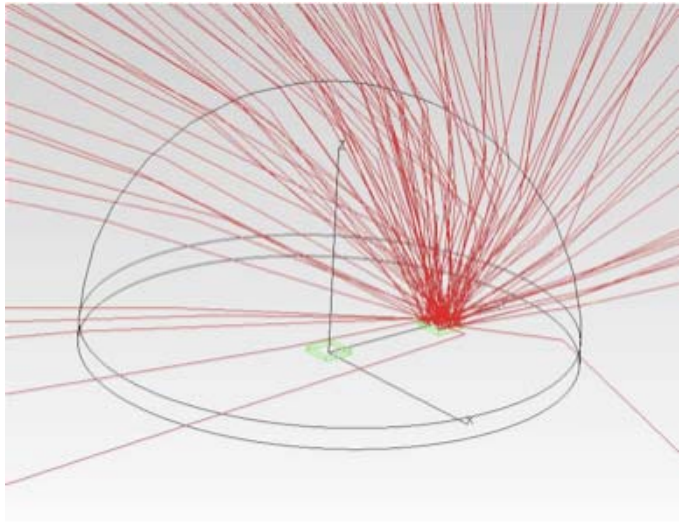
- Larger numbers of smaller die
- Benefits
  - **Optical** - Uniform light output
  - **Electrical** - Lower currents = lower cost LED drives
  - **Thermal** - Lower power density
  - **Packaging** - Potentially lower cost
  - **Efficiency** - Overall improved
- Downside
  - **Yield** - potentially lower due to parts count





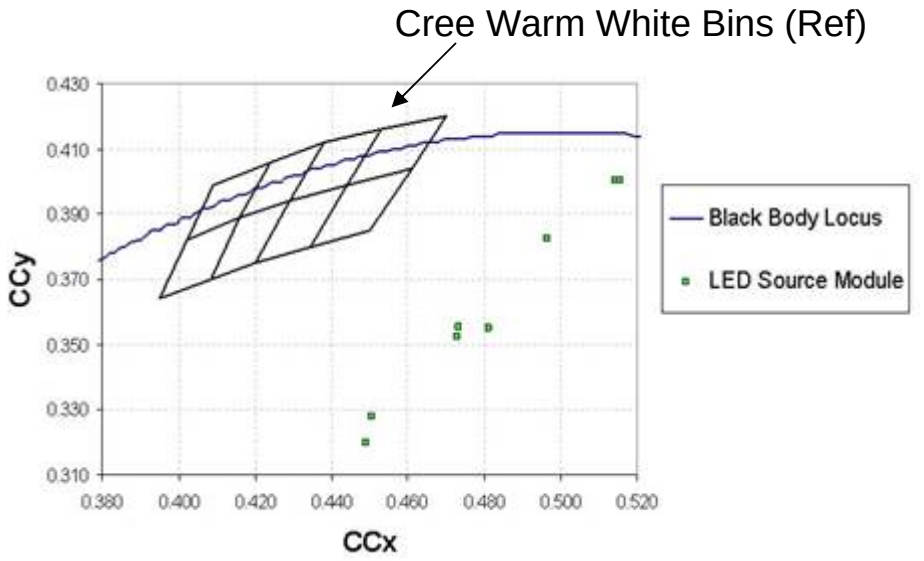
Hybrid LED approach

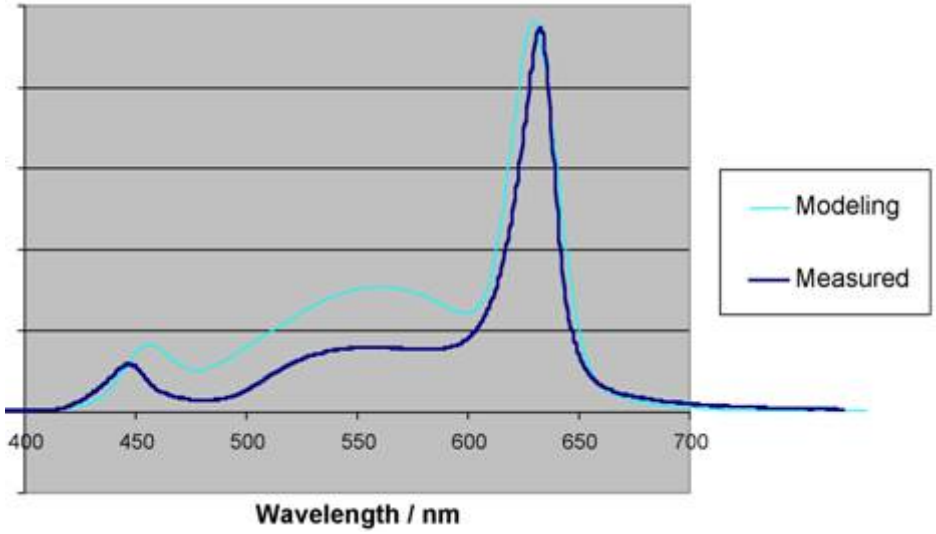
- Mixed PC Converted Blue + Red die
- Simulations showed
  - High efficacy
  - High CRI



Hybrid Approach

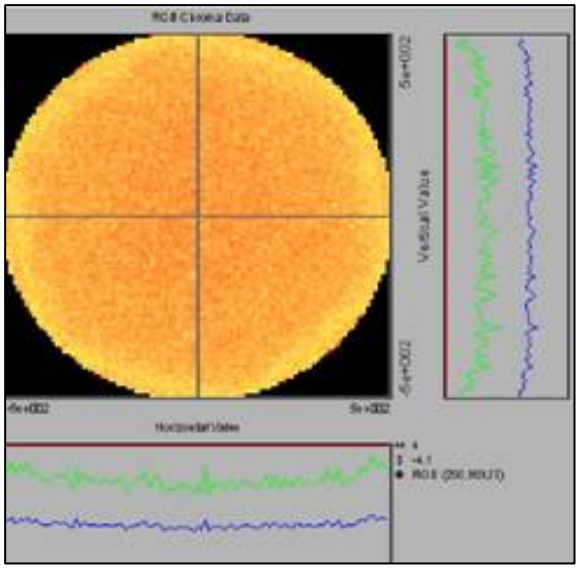
- Mix of phosphor coated and direct emission
- Developed process for selective phosphor coating
- Resultant CCT dependent on
  - Amount of phosphor
  - Flux from direct emission
- Closer to Black Body Curve
- Desirable to have independent control of DE vs PC LEDs

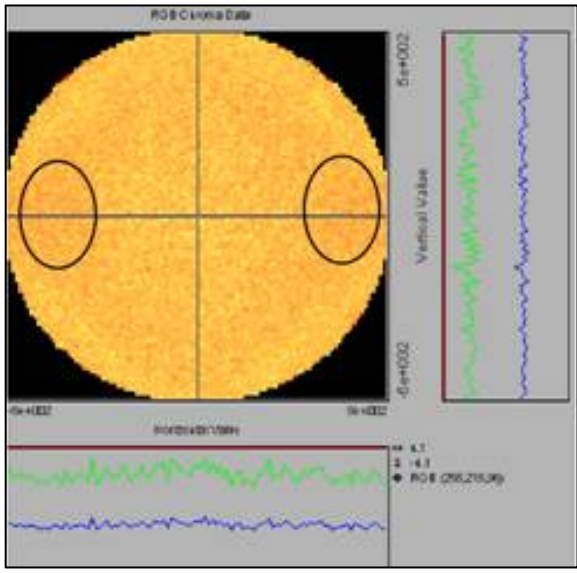


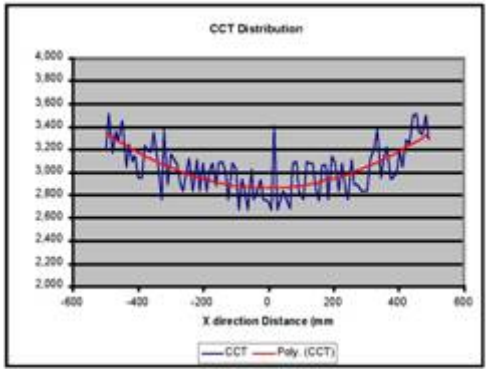


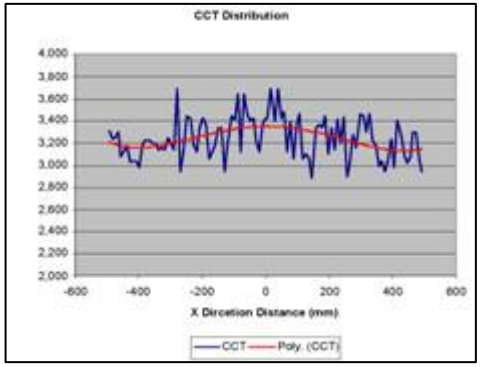
Hybrid Geometry

- Issues include
  - Relative placement
  - Visual artifacts
  - Interconnects
  - Symmetry
- Example simulations and CT ‘cut’ across two configurations



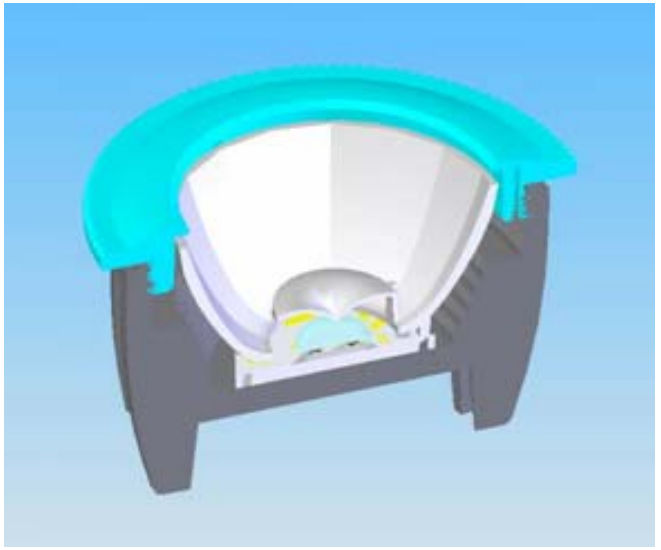


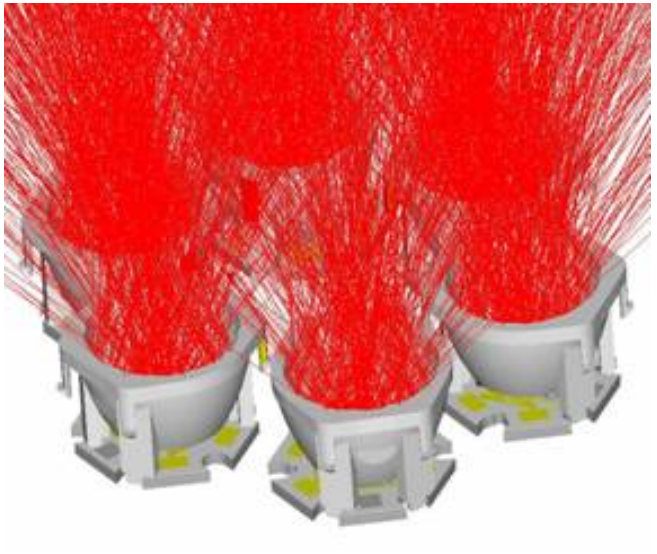




Optics: No photon left behind

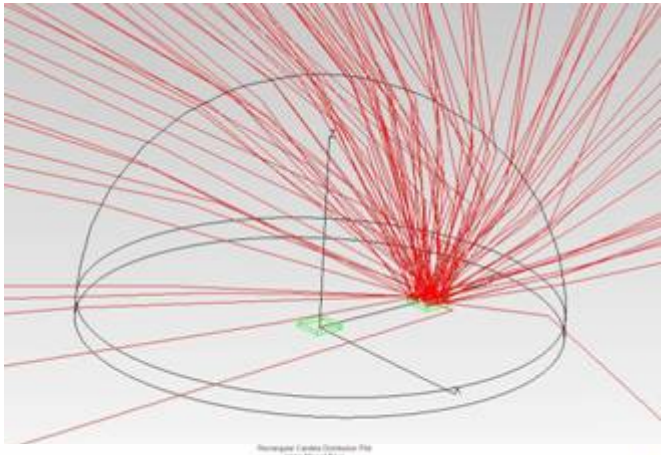
- Good optical design ensures
  - Beam shape appropriate to application
  - No undesirable lighting artifacts and textures
  - Maximizing output
  - Capture of LED output and directing it to where you need it
- One of the most critical design aspects for LED lighting systems

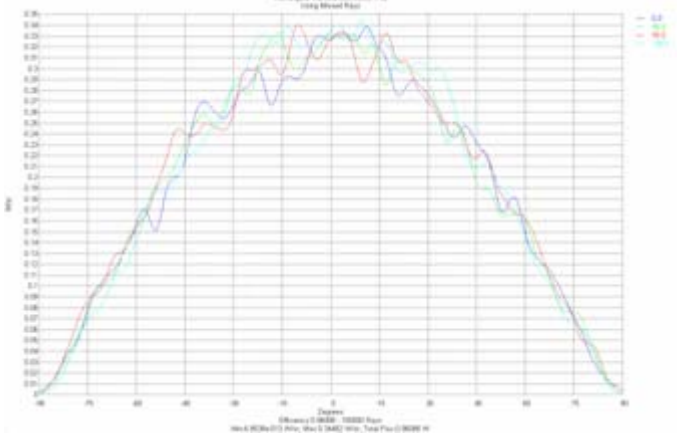




Primary Optic

- Molded Silicone lens
- Large size poses risk
- Need large size to reduce stray losses due to sidewalls
- Needs to register to LED array and to secondary optic
- Approaches
  - Dimensioned Primary lens
  - Ray trace to determine losses
  - Distribution in cut plane



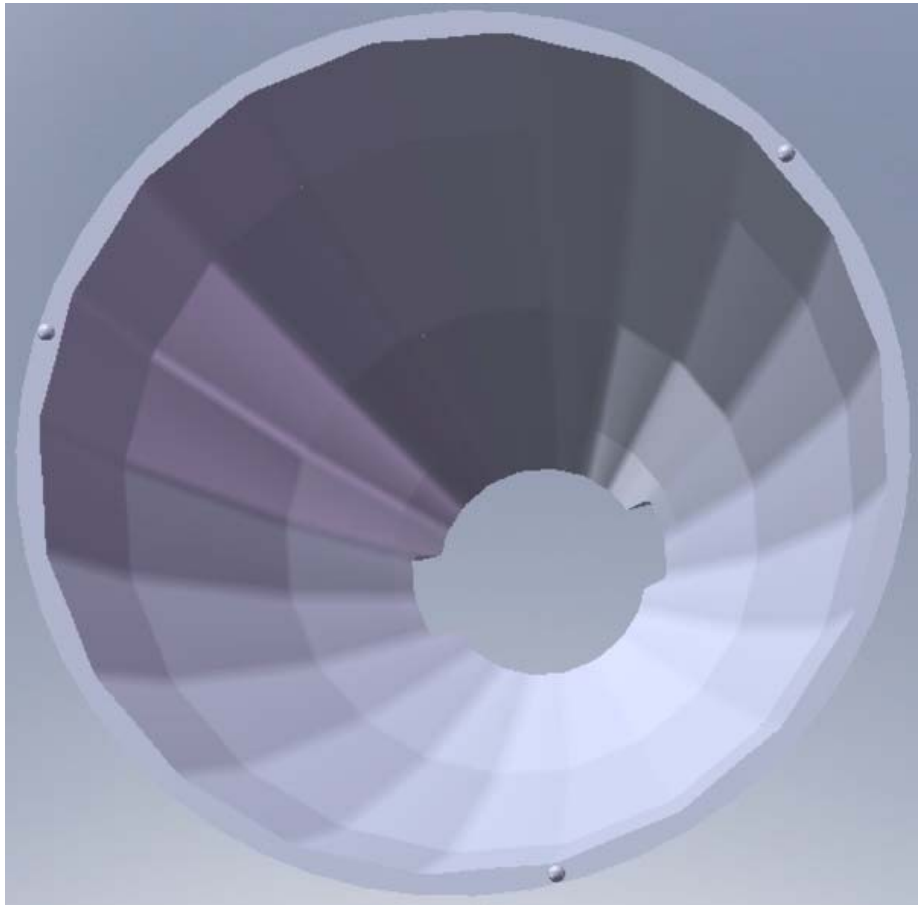


PHILIPS

CREE

Secondary Optic

- Faceted CPC-type optic to capture and direct light
- Molded polycarbonate - metallized
- Low loss, high quality molding and coating
- Registration to mechanical features in LED module



Feed-forward Control

- Additional on-board control in the form of feed-forward model of lumen depreciation
  - Model accommodates aging and thermal characteristics of system through open-loop modeling of system
  - Use knowledge of temperature and time history to feed to model
  - Testing underway now

Performance (Fall)

Metric	Result
Luminous Flux	610 lumens
CRI	86
CCT	2900K
Power Factor	0.9
Efficacy	56 lpw
Beam angle	25 degrees

PHILIPS CREE

Schedule and Milestones - Next

- Critical Pieces over coming months
  - 3rd generation prototype completion and testing
  - Feed forward modeling
  - Continued elevation and evaluation of output
    - Luminous flux
    - Power consumption
    - Efficacy
    - Light quality - distribution, CRI, color
  - Evolve mechanical configuration and thermal analysis
  - Power supply reliability analysis

Thoughts for SSL - Lamp Socket Module